Quarterly Progress Report

For

Mercury Removal in a Non-Thermal, Plasma-Based

Multi-Pollutant Control Technology for Utility Boilers

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Disclaimer

This report describes progress Powerspan has made in the last quarter on specific tasks listed in the Cooperative Agreement. We are currently working on and charging costs to the following tasks:

Task 1: Install and Test Hg Monitoring Equipment
Task 2: Baseline Measurements
Task 6: Determine Processes to Remove Mercury from Liquid Effluent Streams
Task 7: Technology Transfer

Reports on the status for each of these tasks are presented below.

Task 1: Install and Test Hg Monitoring Equipment

The majority of our time and effort to date in this project has been directed towards Task 1. Powerspan has procured, installed and tested two continuous mercury-monitoring systems at our pilot facility. These systems were purchased from PS Analytical (Kent, England) based on our research as well as recommendations of an EPA instrumentation specialist. Each system is composed of two heated sample probes, two sample conditioning / speciation units, a stream switching unit, a calibration unit and an analyzer. The analyzers utilize an atomic fluorescence detector in conjunction with an amalgam trap-and purge method to measure speciated mercury in the flue gas. Typical sample acquisition times range from one to five minutes, based on mercury loading levels. The systems utilize a front-end conditioning / speciation module to differentiate between elemental and oxidized mercury. According to the manufacturer, the mercury CEM systems will not exhibit any interference from other expected flue gases such as water vapor, NO_x, SO_2, CO or CO_2.

The systems are capable of providing near real-time monitoring of inlet and outlet flue gas streams and are capable of extracting samples from different process locations to characterize mercury removal at these different process stages. The five sample points we have chosen are: (1) the system inlet, (2) between the dry electrostatic precipitator field and the dielectric barrier discharge reactor, (3) between the discharge reactor and the scrubbing section, (4) between the scrubbing section and wet electrostatic precipitator, and (5) the system outlet. (See figure 1 below).

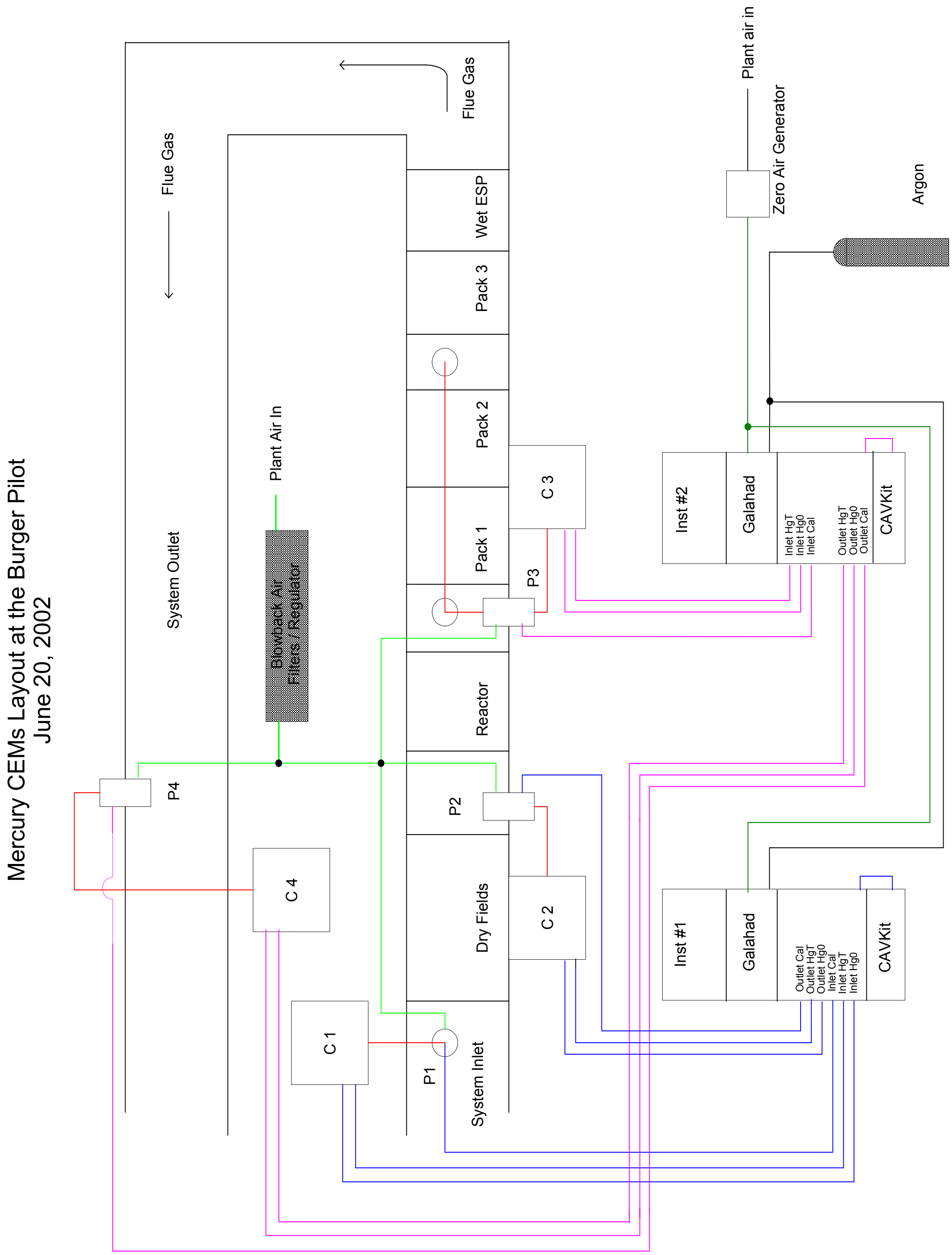

Figure 1: Schematic of mercury sampling system at the pilot. (P1 = probe 1, C1 = conditioner 1 etc.)

Testing and running the two mercury "continuous emission monitoring" systems could be described as problematic at best. The systems are composed primarily of three components: (1) a sample probe, (2) a sample conditioner and (3) a Galahad analyzer. A central computer, located in the instrument rack, controls the system. A flow diagram of a typical (single probe) system is provided in Figure 1 below. In addition to the computer and analyzer, the instrument rack holds a stream selector, allowing us to connect more than one sample probe and conditioner to the analyzer. A Cavkit unit, capable of delivering either zero-air or mercury-laden air to the sample probe, is also included in the system.

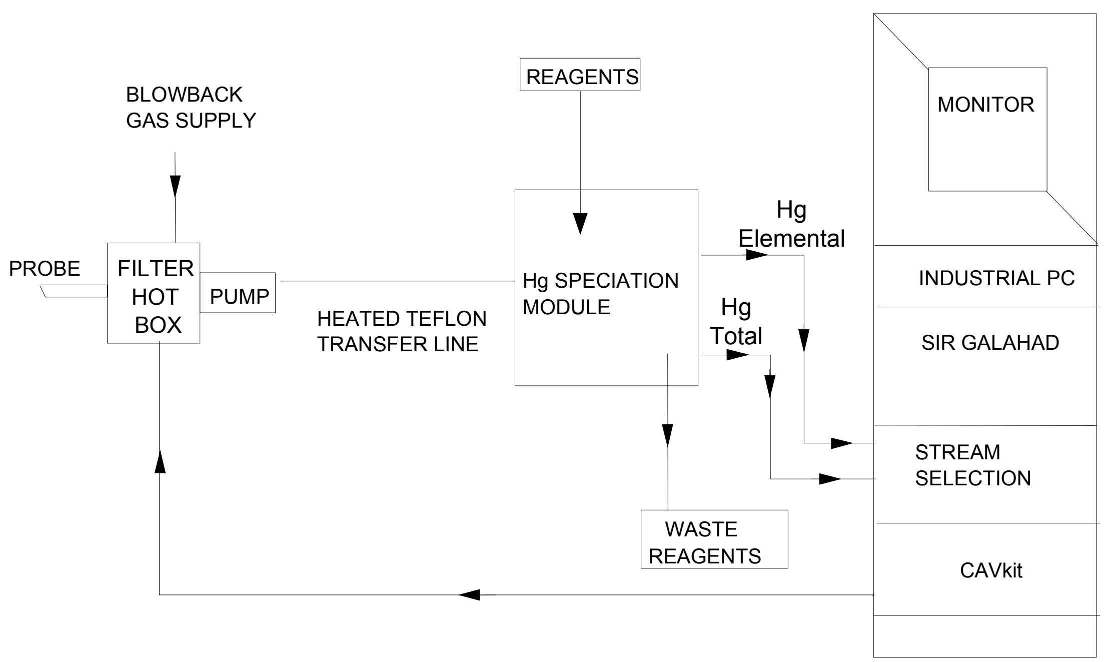

Figure 2: Schematic of a single probe Hg CEM.

We have had a variety of issues with the mercury sampling systems including mechanical, electrical and chemical problems. To begin, control boards in two of the four sample probes were defective and had to be replaced. The control boards regulate the heaters as well as the flow of blowback gas to the filter. In addition to the control boards, Baldwin Environmental personnel reconfigured the wiring regulating the filter blowback feature in all four sample probes. Other sample probe sub-assemblies have had to be replaced as well: in one sample probe, the pump head needed to be replaced due to incorrect assembly on the manufacturers part. We have also had extensive problems with elemental mercury being oxidized across the filters in the sample probes as well. This issue is discussed more completely below. We have had problems with the sample filters and sample lines to the conditioners becoming blocked with ash as well as aerosols. We are currently working with PS Analytical and Baldwin Environmental personnel to resolve these issues.

Each sample probe is connected to a sample conditioner / speciation module via a heated sample line. The purpose of the sample conditioners is three-fold: (1) remove oxidized mercury from the elemental sample channel using an impinger filled with KCl solution, (2) reduce the oxidized mercury to elemental mercury in the Total Hg channel with an impinger filled with $SnCl_2$ and sodium hydroxide and (3) remove excess water vapor from both channels using Peltier thermo-electric coolers. A schematic of a sample conditioner is shown in Figure 3 below. It should be noted that upstream of theimpingers , all Teflon valves, lines and "T" pieces are kept at 400ºF in order to keep the flue gas sample above the dew point.

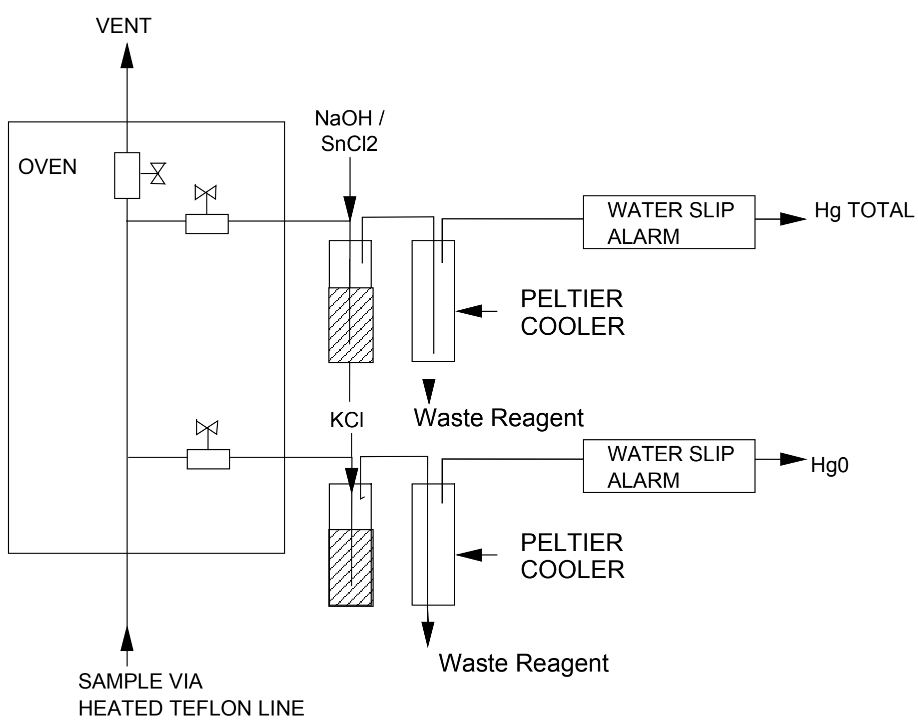

Figure 3: A flow schematic for the sample conditioners / speciation modules.

To date, the speciation modules have been the largest source of problems for the Hg CEM systems. The three valves controlling the flow to the impingers and vent (inside the conditioner heated box) are 100% Teflon and as such are extremely difficult to adjust accurately. Keeping a steady flow though the system with these types of valves has been extremely problematic. The Galahad analyzer draws a slipstream of the supplied flue gas at a rate of ½ liter per minute. If the sample flow rate is below this, the mercury measurements become diluted. On the other hand, if more than one liter per minute of flue gas is sent through the impingers, the condensers cannot remove enough water vapor. The result is that the water slip alarms will activate and shut the unit down, or excess moisture will condense in the sample lines. This excess moisture has twice in the past, made it to the mass flow controller, regulating flow to the Galahad analyzer. The damaged mass flow controllers were removed from the stream selector and sent back to Aalborg for repair and recalibration. We are currently working on a solution to the problem of excess moisture in the sample lines.

When an excess of flue gas (more than one liter per minute) is sent through the Total Hg channel, stannous chloride in the waste reagent reacts with condensed water to form a black precipitate (SnO we think) that eventually clogs the waste impinger. When this occurs waste reagent eventually spills into the water slip detector, activating the alarm and shutting the unit down.

We have found numerous leaks in the sample system, both in the sample probes and the conditioning units. The leaks were difficult to detect and problematic in that in order to get the requisite amount of flow to the Galahad analyzer, excess flow was sent through the impingers. Several of the fittings in the blowback system were also found to leak. While this does not introduce any type of sampling problem, it does cause the compressed air cylinders supplying the blow back air to empty at an alarming rate. We are currently in the process of switching from compressed gas cylinders to a continuous, clean, filtered source of compressed plant air to run the blowback system.

In addition to these problems, on several occasions the reagent impinger tops have exploded showering the inside of the conditioner with caustic reagent. Twice the control boards (regulating the water slips, blowback signals, thermoelectric coolers and temperatures of the heated lines and hotboxes) have been destroyed. Repairs were both expensive and time consuming. A service visit by the manufacturer (Baldwin Environmental) was conducted to install splashguards over the electronics. It would appear that this solution will work well in preventing future damage to the control boards.

We have also encountered a single failure of a Peltier cooler when the ceramic thermoelectric cooler disk cracked. We have also discovered that the coolers are not effective enough in removing moisture from the sample flue gas. Keeping the flow rates of flue gas through the impingers to a minimum helps, but we are still having small problems with moisture condensing in the sample lines leading from the conditioners to the instrument rack. Drip legs will soon be installed and tested on each sample line to prevent water from damaging the mass flow controllers and instruments. In the interim we are drying the sample lines daily with zero-air: a practice that is labor intensive and prone to inviting sample line contamination. As a note: any conditioning unit we might order in the future would have oversized and over-powered coolers.

Keeping the Hg CEM sample lines clear of obstructions has been challenging as well. On several occasions the ECO™ system outlet sample filter has become clogged with fine particles. We suspect these filter clogs are sub-micron ammonium sulfate and ammonium nitrate aerosols. Due to the nature of these aerosols in a near saturated environment, blowback of the filters has not been particularly effective. These fine aerosols have a tendency to react with water vapor to form a viscous mud on the surface of the sample probe filters. We are currently working with Baldwin Environmental and PS Analytical personnel to solve this problem. One avenue of investigation we are pursuing is the use of a different filter types in the sample probe. A discussion of the filter testing to date is provided later in this report.

There have been countless smaller problems with the mercury CEM systems including clogged reagent and sample lines (brought about by dried reagents), electrical faults, leaks, spills, broken impingers, failed solenoid valves and cracked flow control valves. We recently have had two electrical shorts in the conditioner used at the ECO system inlet. The conditioner and sample probe will soon be shipped back to Baldwin for inspection and repair. To help solve these problems and others, we have had two service visits by PS Analytical personnel and two visits by Baldwin Environmental personnel (the manufactures of the conditioners and sample probes) to the pilot facility. Personnel from both of these companies have been very helpful and forthcoming in aiding us in our troubleshooting efforts.

In summary, the two Hg CEM systems have been challenging to operate on a continuous, reliable basis. We have spent a tremendous amount of time and effort troubleshooting, repairing and modifying the Hg CEMs in order to use them continuously. With many of the sampling issues solved, we are in the process of training members of the Powerspan R&D team to run and maintain the instruments. We have found that these instruments are extremely labor intensive and expensive to operate. A more thorough description of the instruments and the problems we have had with them will be included in the technical report after the completion of Task #1.

Evaluation of new filter types

Oxidation of elemental mercury occurs when flue gas is pulled through the reactive layer of fly ash, thereby perturbing the measured ratio of oxidized to elemental mercury. The probes we purchased from PS Analytical came equipped with ½" thick Teflon filters, designed to stop particles larger than two microns. The Hg CEM system filters were designed to be "blown back" occasionally with 90 psi compressed air to clean the filter of ash. Our preliminary tests have indicated that these thick Teflon filters, once dirtied with ash, are very difficult to clean and some oxidation of elemental mercury will occur. We ran a test to illustrate the need to keep the filters clean of ash. At the beginning of the test, a new Teflon filter was installed in the ECO™ system inlet sample probe (in front of the dry electrostatic precipitator). The sample probe was allowed to collect ash-laden flue gas while the instrument blowback feature was disengaged. The seven hours of testing data is shown below in Figure 4. It should be noted that during this test, the mercury vapor addition system was operating and delivering ~4 µg /dscm elemental mercury vapor. (The mercury vapor addition system is described more completely later in the report.)

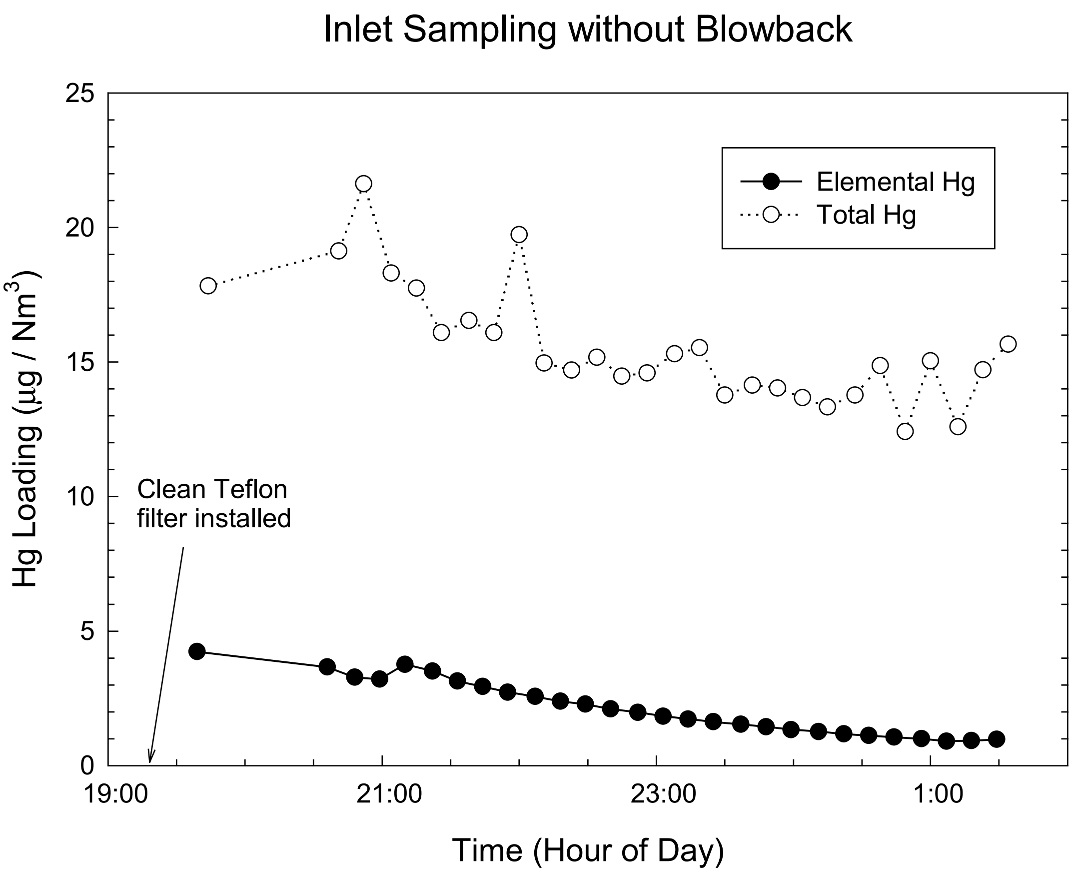

Figure 5: ECO™ system inlet sample data with the blowback feature disengaged. Oxidation of elemental mercury is clearly obvious in the plot.

Clearly, keeping the filters clean of ash is necessary to accurately measure elemental and oxidized mercury in flue gas. John Ward, from Baldwin Environmental, supplied us with a new type of filter to be used in the sample probes of our Hg CEM system. These new filters are composed primarily of a Teflon coated metal screen designed to stop particles down to two microns in diameter. These new metal filters are much thinner than the original Teflon filters, and as such we are expecting the filter blowback to be much more effective. The new metal filters can also be easily removed and manually cleaned of ash and aerosols.

Several tests were run to determine the effectiveness of these new filters. The first test was to use CAVkit gas to compare the performance of the thick Teflon filters with the metal filters. (The CAVkit gas is supplied from the CAVkit unit in the instrument rack and can supply 1-15 µg/Nm^3 of elemental mercury to the outside of the sample probe filters.) A comparison of the two filter types is provided below in Figure 6.

Initial evaluations of filters are fairly positive: The inlet filters, where most of the elemental mercury oxidation was occurring, are fairly easy to keep free of ash. The system outlet filters however are easily clogged with particulate matter. We are currently incorporating frequent blowbacks and filter soakings into our standard Hg CEM operating procedures in order to avoid this problem.

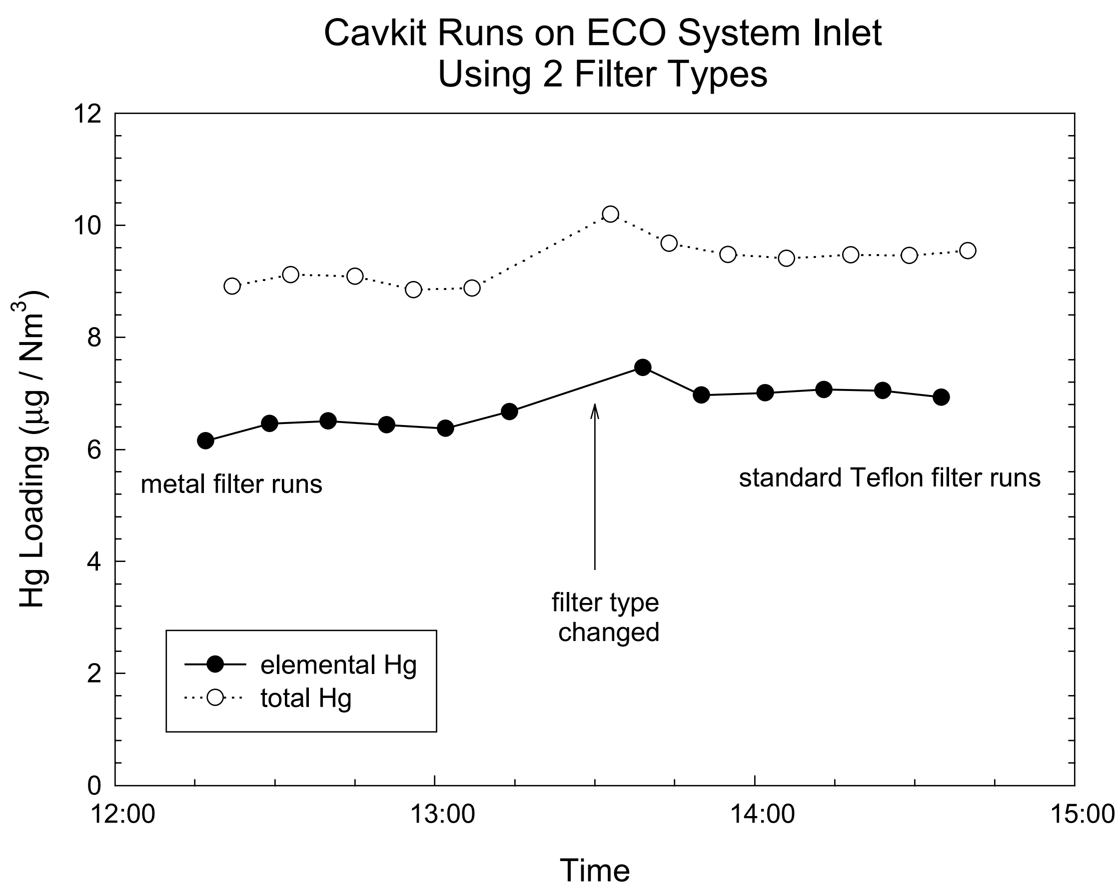

Figure 6: Testing results of new filter types.

We have found that with respect to elemental mercury vapor, the two different filter types performed almost identically. The tests however illuminated another problem we were having: contamination of the heated sample lines running from the probes to the conditioners. Ideally with the introduction of only elemental mercury vapor to the sample probes, the Total Hg and Elemental Hg channels should read identical amounts of mercury. Testing of the filters using CAVkit gas indicated that the Total Hg channel was reading approximately 2.5 μg/Nm^3 higher than the Elemental channel. This lead us to believe that there was contamination of the heated sample line with ash (which would artificially lower the amount of elemental Hg being sampled). The CAVkit units, in addition to supplying the sample probes with mercury-laden air can also supply approximately 30 liters per minute of mercury-free zero air. Figure 7 below illustrates the results of several hours of "blanks" run on the ECO system inlet probe. Typical blanks that we have run in the past have indicated that the elemental Hg levels should be very close to 0.0 μg/Nm^3 and the blank levels in the Total Hg channels should be ~0.2 μg/Nm^3.

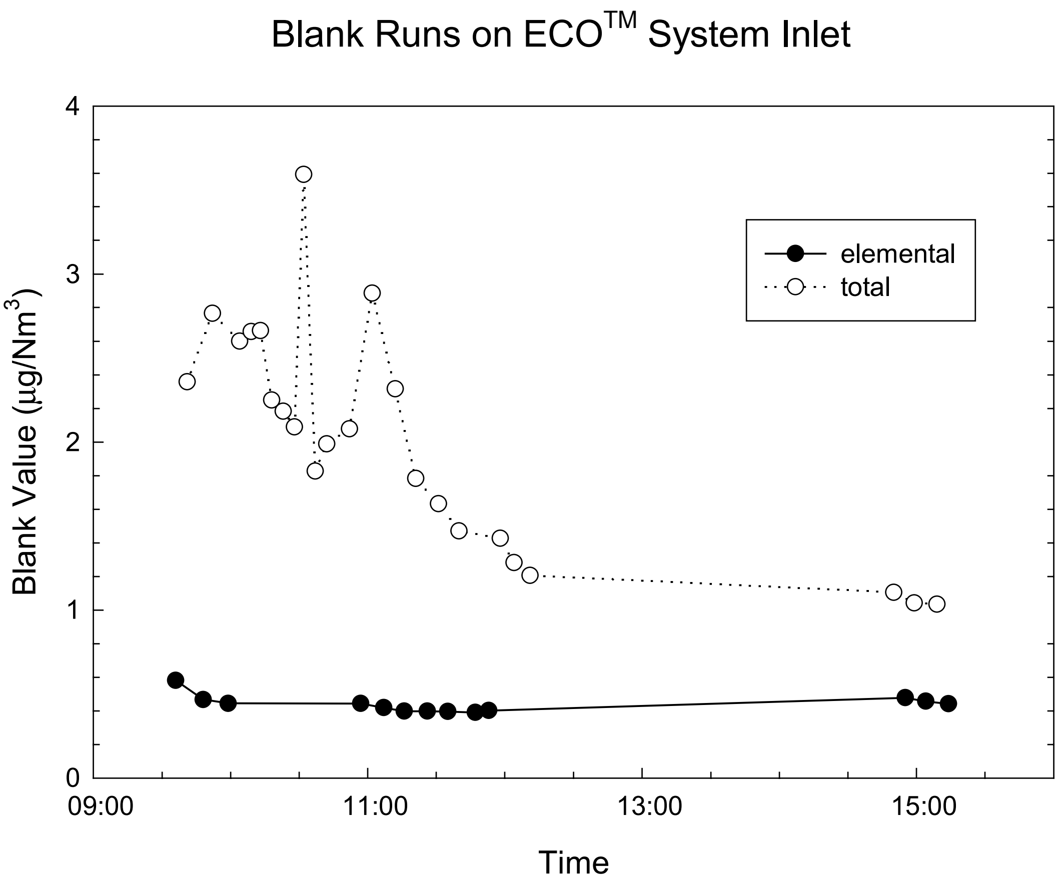

Figure 7: Blank runs on the ECO system inlet. Contamination of the system is clearly evident.

Examination of the inlet heated sample line did in fact show ash contamination. PS Analytical personnel recommend that the sample line be rinsed with a 10% nitric acid solution followed by rinsing with deionized water. This procedure will be incorporated into our weekly maintenance procedures. Along with these weekly cleanings, we expect to perform blank and CAVkit runs on all the conditioners on a daily basis to check for mercury or ash contamination in the sampling system.

It was obvious from early inlet measurements of elemental mercury that there was a need to spike the flue gas with elemental mercury vapor. A system for spiking the flue gas to 5 - 40 μg/Nm^3 of elemental mercury (at a flue gas flow rate of 2500 scfm) was designed, constructed and tested during this quarter. The addition system is centered on a heated reservoir of elemental mercury. Zero air is allowed to flow through the reservoir and a condenser at a rate of 5 liters per minute, then mixed with 200 liters per minute of dilution air. This mercury-laden air is then introduced into the ECO™ duct at a point prior to the cyclone. A plot of initial data taken at the system inlet is shown below in figure 8.

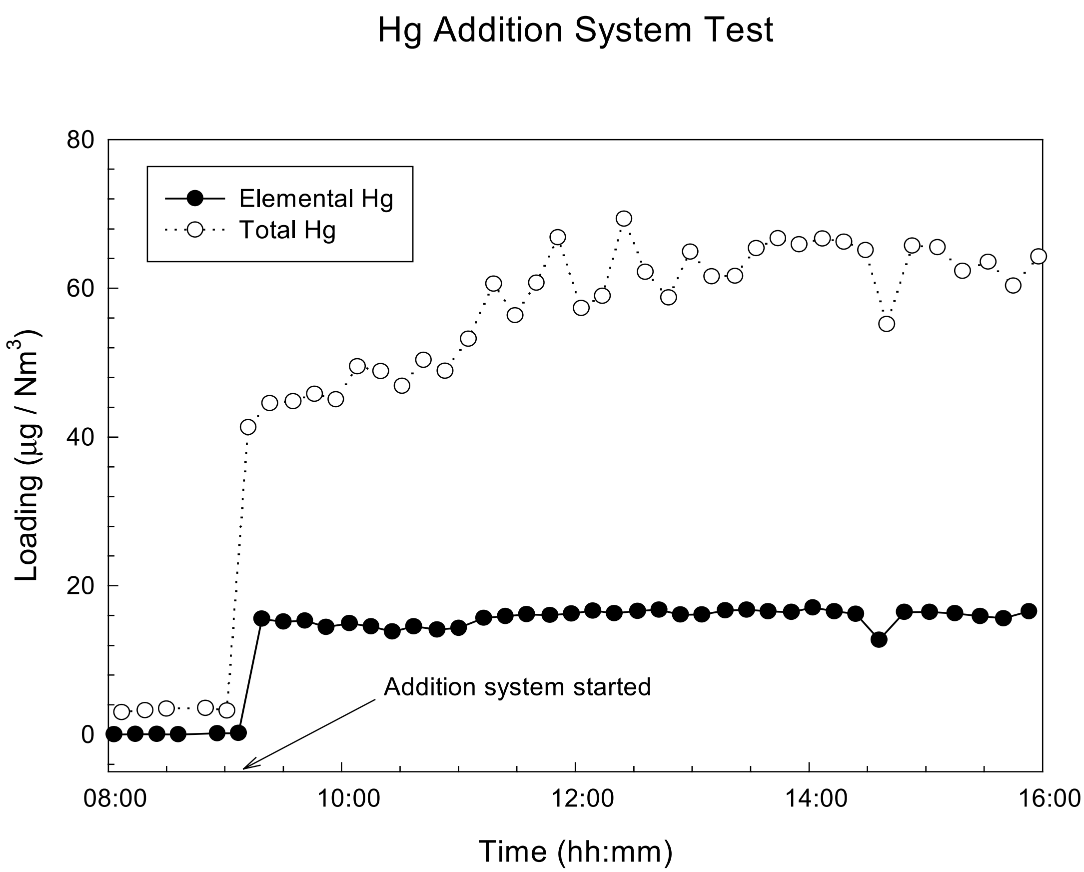

Figure 8: Early test of the mercury vapor addition system.

Typical addition system results indicate the elemental mercury is boosted from 0.5 μg/Nm^3 to 15 μg/Nm^3 and the total mercury from 6 μg/Nm^3 to 60 μg/Nm^3. Early indications are that a large amount of the injected elemental mercury is being oxidized in the inlet flue gas or across the probe filter. We are currently investigating other methods of mixing elemental mercury vapor into the ECO™ flue gas using the existing addition system.

Air Compliance Testing Inc. conducted three days of baseline validation testing of the installed Hg CEMs systems. The validation testing took place during May 8-10, 2002. ACT conducted the validation during twenty-three hours of sampling using the Ontario-Hydro method. (A copy of the Air Compliance Testing report will be sent to DOE.) Three samples were collected at the system inlet consisting of one three-hour run and two four-hour runs. Three samples were also collected at the system outlet each consisting of runs four hours long. During these run times, the two PS Analytical Hg CEM systems were operated using sample probes at the system inlet and outlet. A short summary of the data observed by the PS Analytical instruments is provided in the table below. It should be noted that the mercury vapor addition system was not used during these testing events.

	PSA Elemental μg / dscm	ACT Elemental μg / dscm	ACT Hg^0 Detection Limit	PSA Oxidized μg / dscm	ACT Oxidized μg / dscm	ACT Hg^{2+} Detection Limit
Inlet Run 1	0.53 ± 0.10	<0.52	0.52	3.96 ± 0.68	5.28	0.22
Inlet Run 2	0.06 ± 0.03	<0.35	0.35	4.68 ± 0.75	5.70	0.26
Inlet Run 3	0.19 ± 0.07	<0.42	0.42	5.74 ± 0.75	6.46	0.27
Outlet Run 1	0.58 ± 0.10	0.58	0.48	0.15 ± 0.04	<0.37	0.37
Outlet Run 2	0.40 ± 0.05	0.58	0.38	0.13 ± 0.04	<0.32	0.32
Outlet Run 3	0.45 ± 0.03	1.09	0.37	0.15 ± 0.05	<0.31	0.31

Table 1: Summary of Air Compliance, Powerspan instrument inter-comparison.

During these testing runs, the PS Analytical instruments obtained either an Elemental Hg measurement or a Total Hg measurement once every five minutes. These measurements were blank subtracted (obtained prior to the testing event) and averaged over the time period of the ACT testing run. Calculations of oxidized mercury levels were made by subtracting the PSA elemental Hg levels from the PSA total Hg levels.

Clearly, half the samples obtained by Air Compliance Testing were below the detection limit for the Ontario-Hydro method. As expected, the outlet oxidized mercury levels were low, but still above the PSA detection limits. However, for those runs above the ACT detection limits, the results agree fairly well with the PS Analytical instrumentation results. *The conclusion that we drew from this testing event is that the PS Analytical instruments are fairly accurate in there assessment of elemental and oxidized Hg in the flue gas and will be acceptable for our measurement needs during the course of this project.* We have scheduled another routine series of Ontario-Hydro measurement events with Air Compliance Testing for September 18 – 20, 2002. During these tests however, the mercury addition system will be in operation thereby raising the elemental Hg levels in the flue gas far above the Ontario-Hydro detection limits.

We have connected the two Sir Galahad analyzers to the ECO™ data acquisition system using PS Analytical supplied DAQ cards. We expect shortly to have the two computers in the Hg CEM systems installed with network cards. This, along with PC Anywhere software, will allow us to control many aspects of the Hg sampling from our New Durham location. We expect that adding the Hg CEM computers to our network will substantially improve our ability to obtain continuous, reliable data on mercury speciation and scrubbing in the flue gas.

Several tasks need to be performed in order to complete Task 1. As described by the Cooperative Agreement Statement of Work, we expect to prepare a report identifying the final configuration of the Hg CEM systems and the operating protocols. This report will also document the testing done to demonstrate the adequacy of the protocols. We expect to provide DOE with this report in the very near future.

In summary, for Task 1, we have installed, tested and debugged two independent Hg CEM systems at our pilot facility in Shadyside, Ohio. The two Hg CEM systems have been challenging to operate on a continuous, reliable basis. We have spent a tremendous amount of time and effort troubleshooting, repairing and modifying the Hg CEMs in order to use them continuously. We have found that these instruments are extremely labor intensive and expensive to operate. We have conducted three days of inter-comparison testing using the Ontario-Hydro method and found suitable agreement with the PS Analytical instrumentation.

Task 2: Baseline information

According to the time schedule set forth in the Cooperative Agreement, Task 1 was scheduled to be completed by April 24, 2002. Due to unexpected equipment failures in the Hg CEMs sampling systems and the subsequent delays needed for repairs and improvements, we now expect to complete Task 1 close to the end of June 2002. In order to keep the Powerspan / DOE program on schedule; the start of Task 2 (Baseline information) is expected to begin shortly before Task 1 is completed.

The goal of Task 2 is to fully characterize the incoming flue gas, including the quantity and speciation of mercury and the removal that takes place in the pilots' two dry ESP fields. Through this, we will gain an understanding of the fate of mercury in the system when no ECO Technology components are operating. During this task we are hoping to characterize the variation in mercury levels and speciation that may be expected during parametric and extended operation tests. Instrumentation and sample extraction and analysis will be done using the equipment and the procedures developed in Task 1. In addition to obtaining baseline information, we are currently using this time period to train additional Powerspan personnel in using the two Hg CEM systems.

Task 6: Determine Processes to Remove Mercury from Liquid Effluent Streams

We have completed the design and construction of a prototype filter system designed to remove elemental and oxidized mercury from our liquid effluent streams. This filter system utilizes MERSORB®LW, a commercially proven adsorbent for applications where mercury must be reduced to extremely low levels in water. Preliminary testing of the effectiveness of this adsorbent for removing mercury from the ECO™ effluent stream took place in early June. We are still examining the results of the testing. Details and conclusions of the testing will be provided in the next monthly report. Efforts to identify available processes to remove mercury from liquid effluent streams are continuing and will most likely be ongoing throughout the course of the project.

We are also working towards identifying the chemical configuration of mercury in each effluent stream from the ECO™ process, specifically, the liquid stream from the wet electrostatic precipitator and from the scrubbing sections. FirstEnergy's Beta Lab is analyzing the samples of the liquid and solid effluent streams from the ECO™ process for mercury content. The results of this testing combined with the flue gas measurements will used to perform a mass balance, the closure of which will provide confirmation of the validity of the instrumentation and analysis techniques.

Task 7: Technology Transfer

Task 7, as stipulated in the Cooperative Agreement, is meant to provide for the transfer of information about the ECO™ process to the air pollution control community and to the public in general. To this end, an addition to the Powerspan company website has been completed. The website addition contains background information on the mercury program, a project timeline, a page for periodic project updates and links to other mercury sites (including NETL, EPA and EERC). The Powerspan website addition can be found at http://www.powerspan.com/technology/mercury.shtml.

In March we exhibited and presented an ECO™ update at the Electric Power 2002 Conference and Exhibition at the America's Center in St. Louis. In a session entitled Emerging Multi-Pollutant Control Technologies, Christopher McLarnon, Ph.D., Director of Research & Development, presented an update of ECO technology, including an overview of improvements to ECO accompanied by recent pilot test data. The audience consisted of approximately 65 delegates from generating companies, engineering & construction firms, government agencies, consulting firms, and trade publications. Editors and reporters from Power, Power Engineering, and The McIlvaine Company were in attendance and will be including summaries in upcoming editions. At our 20' x 20' exhibit booth, we displayed our enhanced ECO™ process and discussed recent pilot test results. We received many visitors from generating companies, engineering & construction firms, government agencies, consulting firms, and suppliers.

We have also recently published an article in the May issue of Modern Power Systems entitled "Powerspan's ECO™ Technology: Multi-Pollutant Control for Coal". The article presented an overview of the ECO technology components as well as preliminary pilot results.

During the next quarter we expect to make a presentation at the Air Quality III conference in Arlington, VA. Dr. Chris McLarnon will be presenting a paper "Mercury Removal in a Multi-Pollutant Control Technology for Utility Boilers". We will provide DOE with a copy of the paper prior to the conference.

Multi-pollutant Control Aspect of Program

Pilot testing of updated ECO™ technology is being conducted FirstEnergy's R.E. Burger generating station. The pilot test facility processes 1,500 to 2,500 scfm of flue gas taken as a slipstream from one of the plant's 156-megawatt coal-fired units. The slipstream represents approximately one percent of the plant's total flue gas flow (about a 1 to 2 megawatt equivalent). The pilot configuration includes the following: (1) a cyclone and dry electrostatic precipitator (ESP) to remove most of the ash particles, (2) the ECO Reactor, (3) an absorber vessel—situated horizontally and (4) a wet ESP. The configuration is illustrated in figure 9 below.

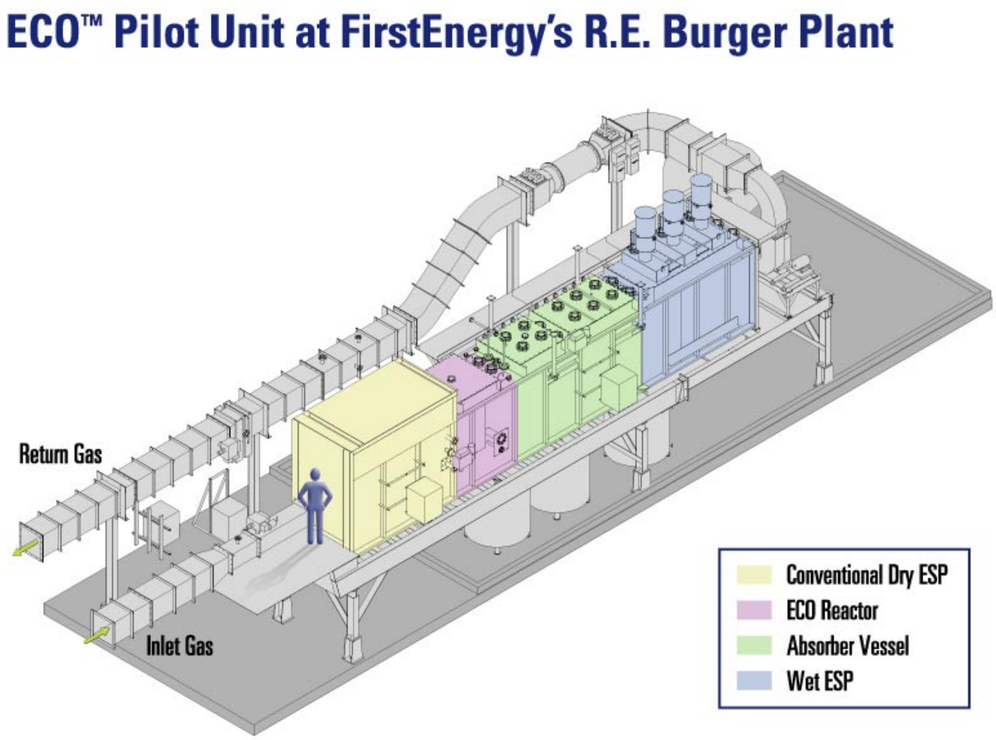

Figure 9: Layout of the R.E. Burger pilot test facility

In addition to these ECO components, the pilot unit contains a full suite of inlet and outlet CEMS (continuous emission monitors) including NO_x, SO_2, O_2, H_2O, CO, and CO_2. New online mercury monitoring systems were added during the first quarter of 2002. The unit is fully instrumented to monitor temperatures and flows. Data logging of the measurements is completely automated. Currently the pilot is showing removals of greater than 95% SO_2 and 90% NO_x, based on 0.4 lb/mmBtu of inlet NO_x.

Financial Information Update

A brief table outlining the budget and expenditures to date is provided below.

Category	Expended Amounts (to date)	Budgeted Amounts (to date)
Personnel	$ 144,847	$ 409,845
Travel	$ 31,090	$ 46,490
Equipment	$ 240,266	$ 257,540
Supplies	$ 84,251	$ 60,750
Contracts	$ 25,805	$ 89,865
Indirect Charges	$ 24,141	$ 63,526
Total Costs	$ 550,400	$ 928,016

Table 2: Budget summary

In Summary

- We have designed, procured, installed and tested two continuous mercury-monitoring systems at our pilot facility in Shadyside, Ohio.
- Based on the results of three days of inter-comparison testing using the Ontario-Hydro method, we found that the PS Analytical instruments are fairly accurate in there assessment of elemental and oxidized Hg in the flue gas and will be acceptable for our measurement needs during the course of this project.
- A system for spiking the flue gas to 5 - 40 $\mu g/Nm^3$ of elemental mercury was designed, constructed and tested during this quarter.
- We have completed the design and construction of a prototype filter system designed to remove elemental and oxidized mercury from our liquid effluent streams.
- We are working towards identifying the chemical configuration of mercury in each effluent stream from the ECO™ process, specifically, the liquid stream from the wet electrostatic precipitator and from the scrubbing sections.
- Preliminary measurements indicate we are removing fairly high levels of SO_2, NO_x and particulates from the flue gas.

Acknowledgments:

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